IS 3023 : 2013

(Reaffirmed 2019)

भारतीय मानक

थर्मल छिडकाव द्वारा बिल्डिंग-अप के लिए अनुशंसित रीति

(पहला पुनरीक्षण)

Indian Standard

RECOMMENED PRACTICE FOR BUILDING-UP BY THERMAL SPRAYING

(First Revision)

ICS 25.160.10

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BUREAU OF INDIAN STANDARDS
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October 2013 **Price Group 7**

Welding Applications Sectional Committee, MTD 12

FOREWORD

This Indian Standard (First Revision) was adopted by the Bureau of Indian Standards, after the draft finalized by the Welding Applications Sectional Committee had been approved by the Metallurgical Engineering Division Council

This standard was first published in 1965. While reviewing this standard in the light of experience gained during these years, the Committee decided to revise it to bring it in line with the present practice.

Metal build-up is a rapid and effective method that can be used to apply almost any metal to a base material. It is used to restore worn mechanical equipment, to salvage mismachined or otherwise defective parts, and to protect metals against corrosion. Compared to original component replacement costs, metal build-up is a low-cost, high-quality method of restoration.

There are two major fields in which thermal spraying find applications, namely, for providing protection to surfaces against corrosion and for building-up surfaces to desired dimensions. In this standard, it is intended to deal only with the latter aspect.

This standard covers recommendations for build-up by thermal spraying. The processes covered are flame spray, high velocity oxy-fuel (HVOF), wire arc spray and plasma spray. The consumables like wire, powder and gases are also covered. The surface preparation prior to spraying which is an important step is covered. Post spraying operations and quality control are also covered.

In the formulation of this standard due weightage has been given to the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. This is met by basing the standard on the following publications:

a) Thermal Spraying-Practice, Theory and Application, AWS Publication-1985.
b) ASTMC 633-01(2008) — Standard test method for adhesion or cohesion strength of thermal spray coatings.

For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS 2 : 1960 ‘Rules for rounding off numerical values (*revised*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

Indian Standard

RECOMMENED PRACTICE FOR BUILDING-UP BY THERMAL SPRAYING

(First Revision)

1 SCOPE

This standard covers recommendations for building-up by thermal spraying. The processes covered are flame spray, high velocity oxy-fuel (HVOF), wire arc spray and plasma spray. The consumables like wire, powder and gases are also covered.

2 REFERENCE

The standard listed below contains provision which through reference in this text, constitutes provision of this standard. At the time of publication, the edition indicated was valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of the standard listed below:

IS No.	*Title*
3073:1967	Assessment of surface roughness

3 SURFACE PREPARATION

3.1 Surface preparation is the most critical step in a thermal spray operation. Coating adhesion quality is directly related to the cleanliness and the roughness of the substrate which depends on the mechanical interlocking of the first layer to the interstices of the roughened surface.

The heat of spraying will not remove contaminants, and contamination will inhibit bonding. Surface must remain uncontaminated by lubricants from handling equipment or body oils from hand and arms after it is prepared. The parts should be protected from airborne debris and fingerprints, and should be handled with clean fixtures and materials. The surface preparation is almost the same for all types of processes.

3.2 Preliminary Cleaning

Grease, scale, oil, paint and other foreign contaminants must be removed from the area to be sprayed as well as adjoining areas, since they stand in the way of proper adhesion of the sprayed metal to the surface.

3.2.1 *Solvent Cleaning*

A chemical solvent, such as, acetone, trichloroethylene or carbon tetrachloride or heating or combination of both methods should be employed for cleaning. The part should be soaked for a period of 15-30 min to remove oil from interstices and surface pores. If objects are too large for soaking then manual cleaning may be employed.

3.2.2 *Abrasive Blasting*

Dry abrasive blasting can be used to remove scales and oxides. Abrasive blasting is accomplished by directing a compressed air stream containing abrasive particles through a nozzle and against the surface of the substrate. Careful consideration is required in selecting the type and size of abrasive.

3.3 Inspection After Preliminary Cleaning

The surface should be carefully examined for freedom from cracks and other flaws. This shall be done with nondestructive inspection methods. Structural flaws in the part will produce similar flaws in the coating, thus rendering it unsuitable for repair.

3.4 Roughening

After cleaning several methods can be employed to produce a surface to which a sprayed coating will adhere.

The principal methods are:

a) abrasive grit blasting;
b) macroroughening; and
c) applying a bond coating.

Combinations of these methods shall be employed. These include grit blasting with a subsequent bond coating, or machine roughening followed by grit blasting.

The degree of roughness required for producing a sound and serviceable coating is dependent upon the material being applied, the process and the subsequent service conditions of the finished part. *See* IS 3073 for measuring surface roughness.

3.4.1 *Abrasive Grit Blasting*

Abrasive grit blasting is the most commonly used roughening technique. The surface to be coated is disturbed by impingement of abrasive particles.

3.4.1.1 *Factors influencing grit selection*

Care must be exercised in grit selection. Factors that must be taken into consideration for proper grit selection include the following:

a) Part material and hardness,
b) Part construction and thickness in the area being grit blasted,
c) Part size,
d) Type of coating and roughness requirement for good adhesion,
e) Service requirements,
f) Grit particle size,
g) Blast pressure and nozzle size, and
h) Ambient conditions.

3.4.1.2 *Abrasive grit type and size*

The effects of grit blasting depend on the type and size of abrasive. Sharp, hard, angular particles provide the best results. Spherical or rounded particles should not be used. All abrasives must be clean, dry and free from oil, or other contaminants.

3.4.1.2.1 *Abrasive grit types*

The most commonly used abrasive for grit blasting is aluminium oxide. It is cubic in shape. The hardness of virgin aluminium oxide is 76 HRC whereas that of reclaimed aluminium oxide is 66 HRC. Virgin aluminium oxide may be used on hard substrates, such as, martensitic steel. When used on soft substrates like copper and copper alloys, low blasting pressure shall be employed or subsequent air blasting may help to remove any embedded particles.

3.4.1.2.2 *Abrasive grit sizes*

Since the roughness of the finish depends on the size of the grit, abrasives are furnished in different grades. Smaller sized particles will allow for the preparation of more area per hour. Larger abrasive particles result in more rapid removal of material from the substrate, and produce rougher finishes. It is recommended that particles size should be 0.25-1.4mm for metal substrates. The general recommendations for grit size selection are given in Table 1.

Table 1 Recommendations Concerning the Grit Sizes Used in Substrate Roughening

Sl No. (1)	Grit (2)	Grit Size (3)	Application (4)
i)	Coarse	–2000 + 600	For coatings thicker than 250 µm and best adherence
ii)	Medium	–1400 + 425	For coatings thinner than 250 µm, fair adherence and smooth surfaces
iii)	Fine	–600 + 800	For coatings thinner than 250 µm, used in 'as-sprayed' conditions (no finishing)

3.4.1.3 *Surface roughness*

The surface roughness required for most spray coatings is 25 µm to 13 µm arithmetic average (AA). For thin metal parts, roughness of around 1.3 µm is recommended.

Adhesion bond strength normally increases with surface roughness, although the rate of improvement decreases above 10 µm.

The best adhesion bond strength is associated with a roughness dimension comparable to three-fourths of the diameter of particles sprayed.

3.4.1.4 *Blasting procedures*

In addition to the abrasive grit type and size, other process variables of importance are air pressure, blast angle, distance, and time.

All substrate areas that can be damaged by the blast operation must be protected by suitable masking (*see* **6.1**).

Dust or grit adhering to the substrate surface must be removed by air blast before starting a spraying operation.

Air pressures for blasting are in the range of 30 to 100 psi (2.1 to 7.03 kg/cm^2), depending on the substrate material; the required surface finish; the flow, weight, and size of abrasive particles; and the machine and nozzle type used. Low blasting air pressures and soft or fine grit should be used for substrates, such as, aluminium and copper alloys, bronzes, to minimize the likelihood of embedding the grit.

High air pressures, in addition to rapid breakdown of grit produce compressive stress which can distort thin substrates.

Grit equipment used for metal spray should not be used for other purposes because dirt, paint, paint and lubricants contaminating the grit can redeposit on the grit blasted surface.

Care must be taken to ensure that substrate is free from traces of residual grit which adversely affect coatings.

3.4.1.5 *Grit recycling*

Abrasives can be recycled, cleaned and screened so that they can be used again. When an abrasive is reused, it should be cleaned of dust and resized, with a minimum of 80 percent conforming to the original size requirements. Contaminated abrasive grains, or those of questionable quality should not be reused.

3.4.2 *Macro-Roughening*

Macro roughening is another surface preparation method usually accomplished by machining or grinding, and is performed in conjunction with grit blasting, the use of bond coating, or both.

3.4.2.1 *Undercutting*

Undercutting is the operation of machining or grinding away surface to provide space for the thermal spray deposit. It removes some good material as well as the damaged surface in order to provide uniform flat surface to accept the new coating. It is almost always necessary to undercut the surface to be built-up.

This is done in order to allow for an adequate and uniform thickness of sprayed deposit on the finished job.

It should also be carried out to remove metal from surface affected due to work hardening, chemical contamination, and oxidation.

Undercutting reduces the effective cross-section of the part to be metal sprayed.

Since sprayed metal deposits do not restore any qualities, such as, tensile strength or resistance to fatigue stress, all parts to be built-up by thermal spraying should be examined carefully from a design standpoint to determine that adequate strength is maintained in the part as prepared for thermal spraying.

3.4.2.1.1 *Procedure*

The undercutting is accomplished on a lathe or similar device by either machining or grinding to the required dimensions, care must be taken to see that the undercut section is concentric with the original axis of the shaft.

In cases where the degree of initial wear is such that adequate amount of metal needs to sprayed to get required thickness of metal deposit, machining or grinding should be done solely for the purpose of correcting the eccentricity in the wear.

The undercutting operation should be preferably done dry, but where this is not feasible it should be followed by a further degreasing treatment and drying.

3.4.2.1.2 *Length of undercut*

The length of undercut section should generally extend beyond both ends of the sleeve, bearing or packing gland in which the shaft operates.

3.4.2.1.3 *Depth of undercut*

The depth to which the shaft should be undercut is determined by a number of factors, such as, the diameter of the shaft, the severity of service and the amount of wear to be expected in service. In general, the minimum specified depth of the undercut should be at least equal to the recommended minimum thickness of the coating, plus the wear or corrosion tolerance for the application. In any case it shall not be less than 0.5 mm.

3.4.2.1.4 *Ends of undercut*

The sprayed metal requires to be mechanically anchored into the base metal at the ends of extremities of the undercut section. The ends of the undercut should be at 15° to 45° to the base metal (*see* Fig. 1).

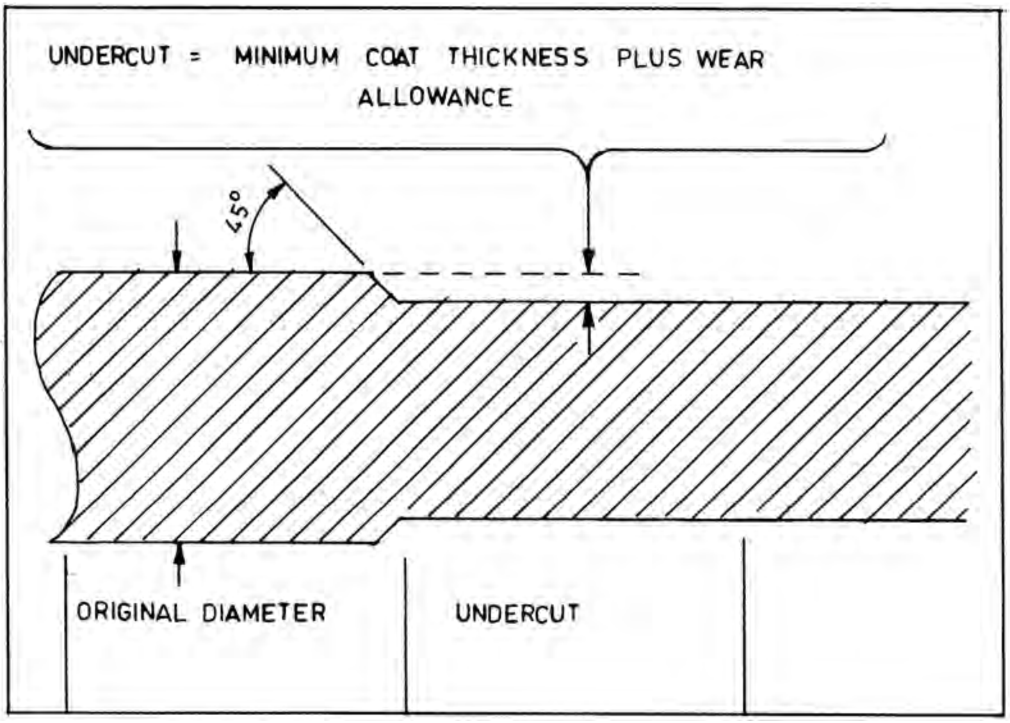

FIG. 1 ENDS DEPTH OF UNDERCUT

3.4.2.2 *Surface roughening*

The undercut section shall be roughened to ensure good bonding between the sprayed coating and the base metal. Before the roughening operation is commenced, it should be made certain that all traces of oil, grease and other foreign matter on and adjacent to the undercut surface are removed. The cleanliness and roughness greatly affect the strength of the bond between the base metal and the sprayed coating.

The roughening operation is carried out on a lathe. Narrow low pitch shallow grooves or threads are cut on the undercut surface. The work should be rotated such that 6 to 12 threads/cm, with a depth of 0.5 to 0.8 mm each, are cut. A 90° cutting tool with a rounded tip should be used for this purpose. Large diameter shafts usually require coarser threads which would also be correspondingly deeper. The threading operation may be done in one or more passes or cuts. No coolant should be used and the surface should always be kept free from grease.

In case of grooving the machining time may be reduced by use of multiple cutters which permit the making of several grooves at a time. Grooving should proceed from both ends towards the centre so that an outsize groove or land, if it occurs, is in the centre of the area to be sprayed. The grooving should cover entire length of the undercut section except for 0.6 to 0.9 mm at each end.

3.4.3 *Bond Coating*

The use of bond coating is another method of surface preparation, which is based on the fact that a thin layer of bonding material serves as an anchoring subcoat for subsequently applied coating layers.

It is particularly applicable for substrates that are too thin or too hard to be prepared by abrasive grit blasting or macro-roughening. They are also applicable when size or configuration makes blasting or roughening difficult.

3.4.3.1 *Procedure*

The bond coating involves applying by metal spraying a thin coating of the bond coating material on to the surface.

The surface should be clean, free from grease and slightly roughened with medium grade emery cloth. A light grinding cut or light grit blasting is usually adequate. Grit blasting is definitely of benefit in that it produces compressive stresses in the surface of the steel and offsets the tendency to the lowering of the fatigue strength. The bond coating should be sprayed coarse since such a coating provides a better key for the following coat. The operating conditions recommended by manufacturers of the thermal spraying equipment should be carefully followed. Since the bond coating material sticks even to smooth surfaces, it is necessary to mask areas adjacent areas of the portion to be treated with tape or a masking compound. Oil holes in the area to be treated should be protected by the use of carbon, wood or brass plugs and keyways by inserting a brass, bronze or carbon dummy key.

3.4.3.2 *Bond coat thickness*

The bonding material shall be applied sufficiently thick to cover the substrate, usually 0.08 to 0.18 mm. It should also be remembered that there is no practical economic or engineering advantage in a thick bond coating.

3.4.3.3 *Bond coat materials*

Commercially available bonding materials include nickel-aluminium composites and alloys which produce some metallurgical interaction with the substrate during spraying. Table 2 lists common bond coating materials and their service temperatures. Nickel-aluminium has good high temperature properties and can be easily applied to various substrates.

Table 2 Approximate Maximum Dervice Temperature Limits for Bond Coatings

Sl No. (1)	Bond Coating (2)	Temperature °C (3)
i)	80 Ni-20 Al	620
ii)	95 Ni- 5 Al	1 010
iii)	80 Ni-20 Cr	1 260

3.4.3.4 *Process specific bond coating*

3.4.3.4.1 *Wire arc spray*

The inherently high adhesive bond strengths achieved with the electric arc process make it possible to eliminate surface roughening for certain applications by using bond coating of nickel-aluminium alloy. This, however, should be an exception rather than the rule. Surface roughening as described previously is always recommended.

3.4.3.4.2 *Flame spray*

Grit blasting and bond coating are usually required for most applications using flame spraying (both wire and powder) because of the low heat of combustion and low particle velocities.

3.4.3.4.3 *Plasma spray*

Roughening (grit blasting) and bond coating are both essential for plasma processes.

4 EQUIPMENT

The certification and verification of equipment to apply coatings may be through calibration of meters and gauges, or through demonstration of coating application. A combination of these methods proves most suitable. Electrical meters are easy to calibrate. The instrument/ equipment shall be installed in a test rig and its performance evaluated against known standard. Gas flow and pressure gauges should be similarly calibrated with a known standard. The equipments used for different thermal spraying process are described below.

4.1 Flame Spray

4.1.1 *Wire Flame Spray*

The equipment for wire spraying is shown in Fig. 2. A typical wire thermal spraying gun cross-section is shown in Fig. 3. The feedstock material is drawn by drive rolls into the rear of the gun. Suitable means of adjustment of feed speed are also provided. The rolls are powered by an electric motor, an air motor, or an air turbine. The feedstock proceeds through a nozzle where it is melted by a coaxial flame of burning gas. One of the following fuel gases may be combined with oxygen for use in flame spraying: acetylene, propane, LPG or natural gas. Acetylene is widely used because higher flame temperatures are attainable. Table 3 gives the temperature attained by different fuel gas-oxygen combinations. A fuel gas flame should be used for melting only, and not for propelling or conveying the coating material. The flame shall be surrounded by a stream of compressed gas, usually air which atomizes the molten metal and propels onto the substrate. In special applications, an inert gas may be used. Oxygen and fuel gas flow controllers should be used to provide good control of the gas ratios and flame intensity. An adequate supply of dry air at optimum operating pressures shall be arranged. Care should be taken to prevent oil or water from mixing with compressed air to prevent fluctuations in the flame which results in poor or irregular atomization of spray material, reduce bond strength and affect the quality of deposit. Other ancillary equipments like pressure regulators and hoses must be arranged.

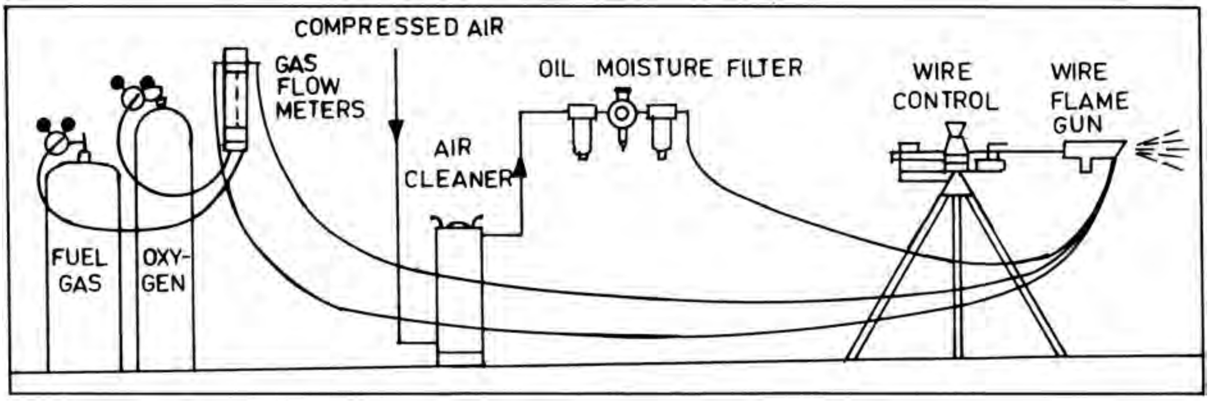

FIG. 2 TYPICAL WIRE FLAME SPRAYING INSTALLATION

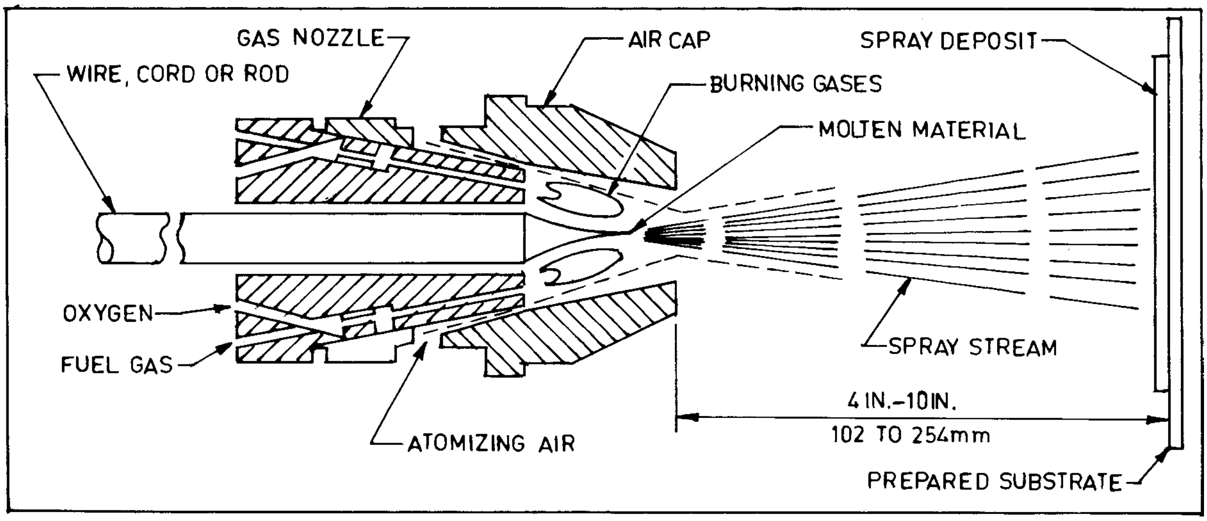

FIG. 3 CROSS-SECTION OF TYPICAL WIRE FLAME SPRAY GUN

Table 3 Heat Source Temperatures

(*Clause* 4.1.1)

Sl No.	Source	Temperature °C
(1)	(2)	(3)
i)	Propane-Oxygen	2 640
ii)	Natural Gas-Oxygen	2 735
iii)	Acetylene-Oxygen	3 100

4.1.2 *Powder Flame Spray*

The equipment for powder flame spray is shown in Fig. 4. A typical powder flame spraying gun cross section is shown in Fig. 5. Powder flame spray guns are lighter and compact than other types of thermal spraying equipment. The coatings produced generally are of lower adhesive strength, lower overall cohesive strength, and higher porosity than coatings produced by other spraying processes. The feedstock is stored in a hopper may be integral with or connected to the gun. A small amount of gas is diverted to carry the powder into the oxygen-fuel gas stream, where the powder is melted and carried by the flame onto the substrate. Additional air jets may be used to accelerate the molten particles. In special cases a remote powder feeder with an inert gas can also be used to convey powder through a pressurized tube into

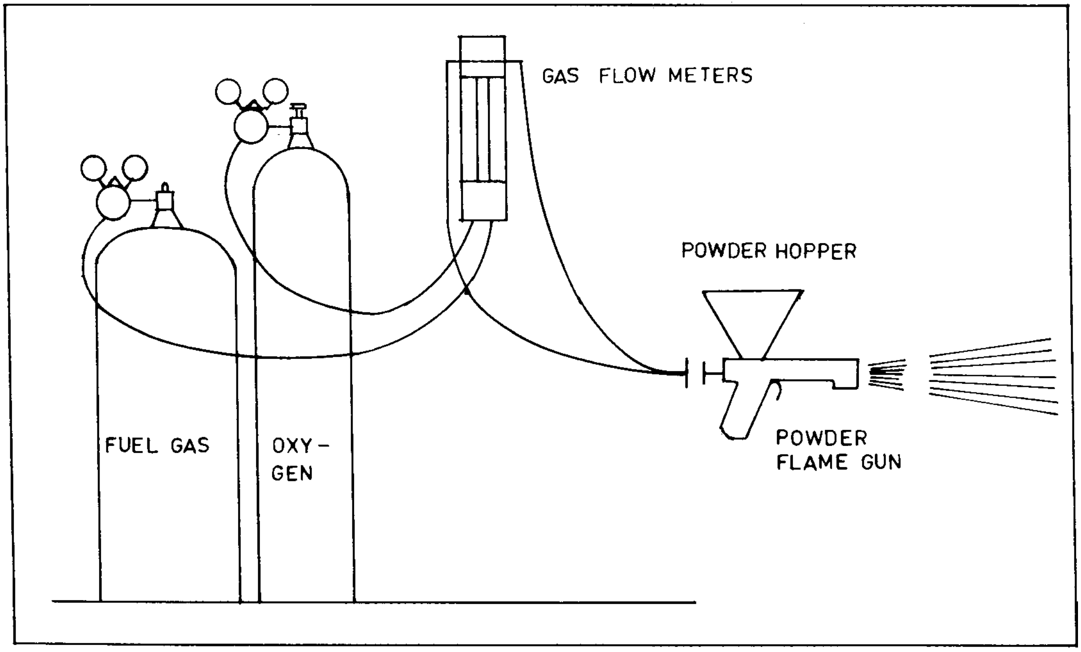

Fig. 4 Typical Installation of a Powder Flame Spray Process

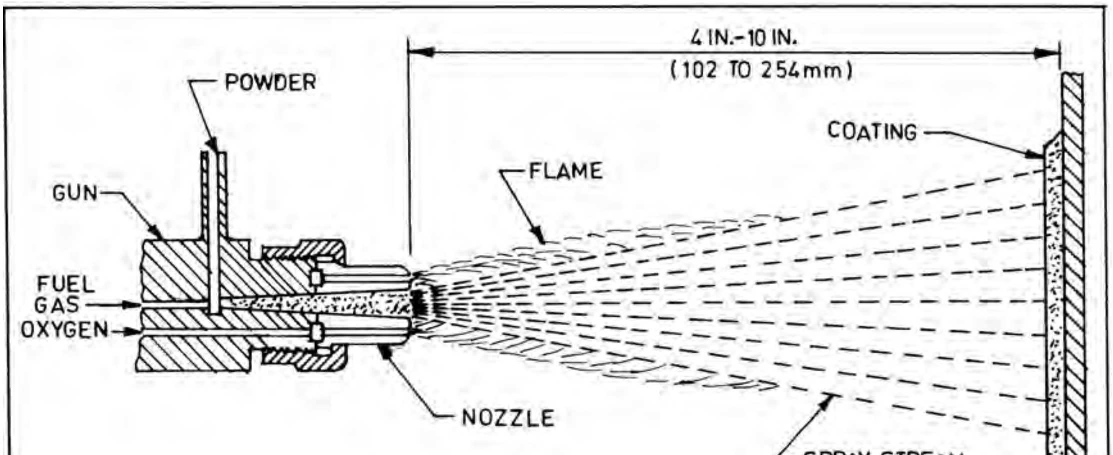

Fig. 5 Cross-Section of a Powder Flame Spray Gun

the gun. Such refinements tend to improve powder flow rate, bond strength and spray deposit density. Powder particle velocity and feed rate affects the structure and the deposit efficiency of the coating. Hence, proper care must be taken to heat the raw material, which will otherwise lead to decrease in deposit efficiency and trapping of unmelted particles in the coating. If the particle velocity is too low, some powder may be volatized and result in coating deterioration and increase in operating cost. A typical powder feeding device must contain a container and a metering device which regulates the feed rate of the material into the carrier gas stream. This process uses the same combustion principles as described for flame spraying with wire.

4.2 High Velocity Oxy-fuel (HVOF)

HVOF spraying differs from conventional flame spraying in that combustion occurs at higher pressure inside the gun, with the resulting flame accelerated along a nozzle to achieve very high velocities. Gas flow rates and delivery pressures are much higher.

A schematic of HVOF is shown in Fig. 6. All HVOF spraying equipment uses oxy-fuel combustion to heat a coating material, in powder form, and to accelerate the heated particles to very high velocities before impacting with the substrate. The combination of high fuel and oxygen flow rates, and high pressure in the combustion chamber generates a supersonic flame with characteristic shock diamonds. Flame speeds of 2 000 ms^{-1} and particle velocities of 400-800 ms^{-1} are typically obtained. A range of fuels can be used, including propylene, propane, hydrogen, acetylene and kerosene (a liquid fuel). The major differences between current commercial systems include: use of gas or liquid fuels; water or air cooling; axial or radial powder injection; combustion chamber configuration; and nozzle design and length. Operational differences comprise combustion pressure, fuel and gas flow rates and powder feed rates. These parameters will determine powder particle heating time and temperature, and ultimately the coating quality. With appropriate equipment, operating parameters and choice of powder, coatings with high density and with bond strengths exceeding 69 MPa can be achieved.

4.3 Wire Arc Spray

The wire arc process uses two consumable electrodes which are initially isolated from each other but automatically advance to meet at a point in an atomizing gas stream. The arc initiation is done by application of potential difference between the two consumable electrodes, resulting in the melting of the electrode tips. The potential difference is around 18-40 V. Usually compressed air is used as the atomizing gas which is directed across the arc zone. The compressed air shears the molten metal into atomized spray of molten droplets. This process is limited to wires made of materials that can conduct electricity. The components of the wire arc spray system are shown in Fig. 7.

4.3.1 *Arc Spray Gun*

The spray gun is illustrated in Fig. 8. The wire electrodes (1), are fed through the wire guides (2), and into the contact tips (3). The atomizing nozzle (4), conducts the compressed air (5), and directs it across the arc zone. Insulated power cables connect the gun to the dc power source. Arc guns also include mechanisms for feeding the wire at a controlled rate. Contact tips are sized for a particular wire diameter. 'ON' and 'OFF' switches are provided on the gun to control the wire feed, compressed air supply, and electric power supply. The arc temperatures considerably exceed the melting point of the spray material. This leads to high particle temperatures and can cause volatilization particularly in aluminium and zinc. The high particle temperature produces metallurgical interactions or diffusion zones, or both, after impact with the substrate. These localized

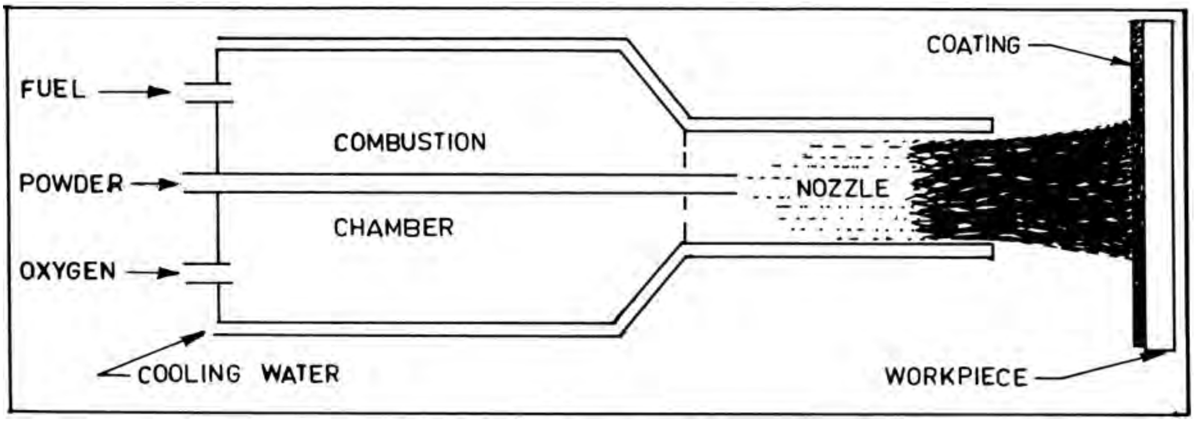

FIG. 6 SCHEMATIC OF HIGH VELOCITY OXY-FUEL PROCESS

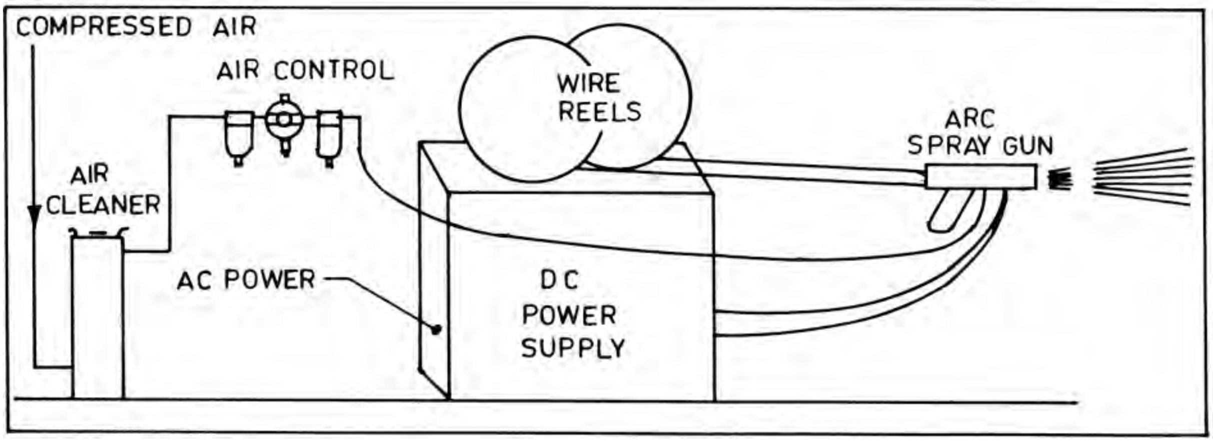

FIG. 7 WIRE ARC SPRAY COMPONENTS COMBINED INTO A SINGLE UNIT

reactions form minute weld spots with good cohesive and adhesive strengths. Thus, the coatings develop excellent strength. The wire spray process normally has higher spray rates than other processes. The application rate depends on the current rating of the power source and the permissible wire feed rate to utilize the available power.

4.3.2 *Power Source*

A dc power source providing a voltage between 18-40 V is recommended for wire spraying. Such a source permits operations with various metals and alloys. Constant voltage sources should generally be used, because arc gap and spray particle size increase with increase in voltage. The voltage shall be kept at the lowest level, consistent with arc stability, to provide smooth and dense coatings.

4.3.3 *Wire Control Unit*

The wire control unit is comprised of two reel or coil holders, which are insulated from each other. Wires of larger diameters are usually in coil form, while smaller diameter wires are preferably layer level wound on reels or in barrels. The unit is connected to the gun by flexible insulated cables.

4.3.4 *Control Console*

The control console incorporates the switches and regulators necessary for controlling and monitoring the operating circuits that power the gun.

4.4 **Plasma Arc Spray**

This process uses powdered materials and plasma as heat source. Plasma generators provide controllable temperatures well in excess of the melting range of

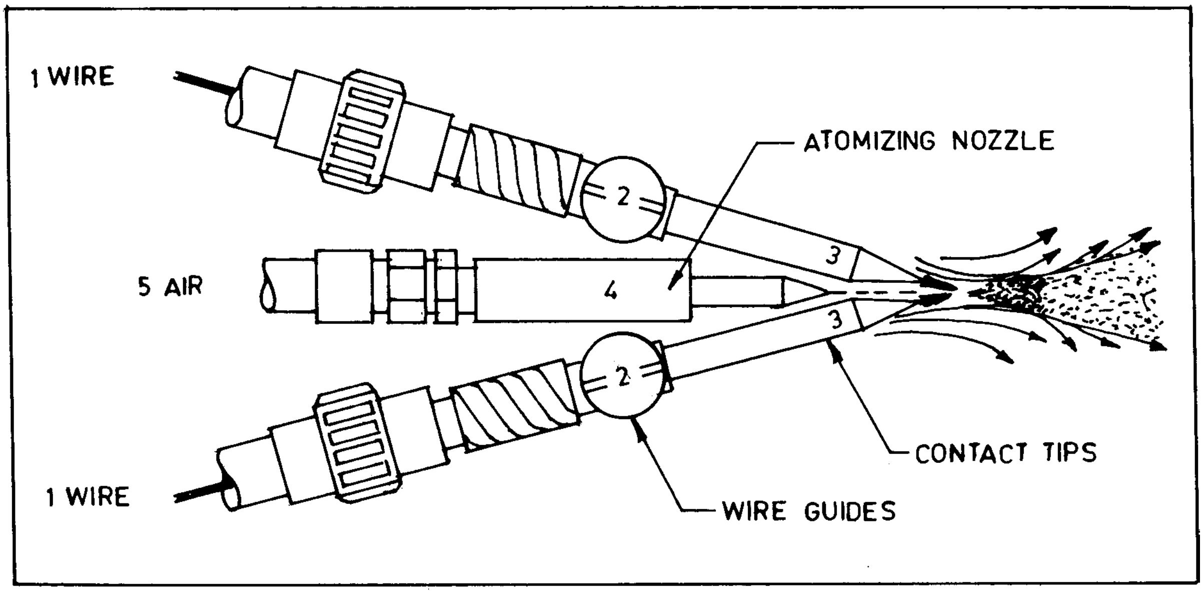

FIG. 8 CROSS SECTION SCHEMATIC OF AN ARC SPRAY GUN

most substances. In this process, a gas or gas mixture is passed through an electric arc between a coaxially aligned tungsten cathode and an orifice in a copper anode (*see* Fig. 9). During heating the gas is partially ionized, producing plasma. The gas ions and electrons recombine as they exits plasma to form gas molecules again liberating heat. The powder is introduced into the plasma, melted, and propelled onto the work piece by a high velocity stream. The heat content, temperature, and velocity of the plasma jet are controlled by the nozzle type, the arc current, the mixture ratio of gases, and the gas flow rate. The arc operates on direct current from a rectifier type power supply. The electric power to the arc is governed by a central control unit that also regulates the flow of plasma gas and cooling water, and sequences these elements to allow the process to be carried out reliably and precisely (*see* Fig. 10). Either nitrogen or argon is used as the primary plasma forming gas. A secondary gas, either hydrogen or helium, may be added to increase heat content and velocity of the plasma.

5 CONSUMABLES

5.1 Wires

The wire used in spraying shall always be certified for

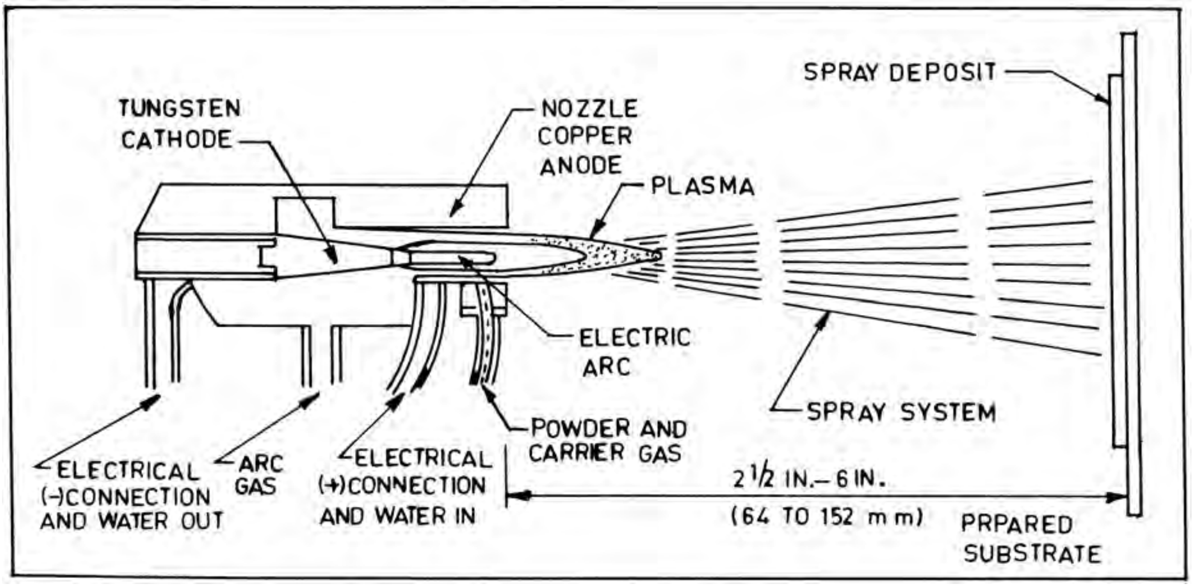

FIG. 9 SECTIONAL VIEW OF PLASMA TORCH

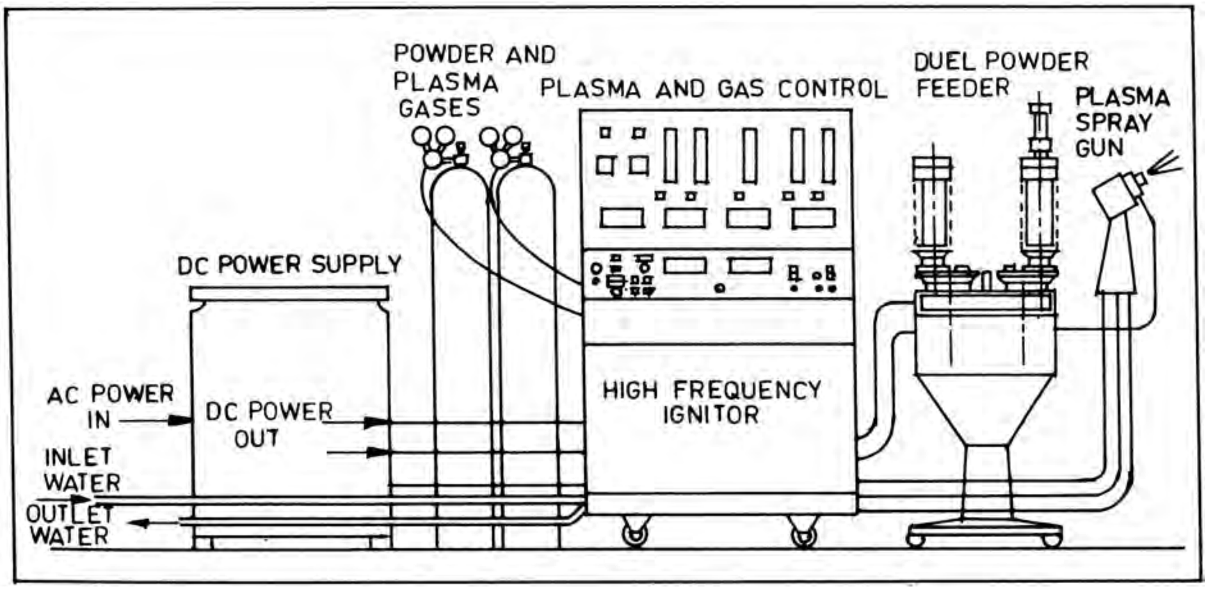

FIG. 10 COMPLETE INSTALLATION OF PLASMA SYSTEM

coating applications. Some of the requirements are:

a) Chemical composition,
b) Physical dimensions,
c) Surface appearance,
d) Physical condition and strength, and
e) Camber or cast.

The roundness and diameter of the wires have direct effect on sprayability and feed. Oversized wires may not feed properly. Care should be taken to check that the wires are not oval shaped or loose fitted, because they cause combustion gases to flow backwards, behind the nozzle, into the drive rolls. This may result in fire, explosion or both. Wire should be in the range of $^{+0}_{-0.70}$ mm of the indicated nozzle bore diameter. Wrought spray stock should be clean, have a smooth surface, and be free of shavings, nicks, or kinks which may cause binding within the nozzle. The material should not be oxidized, corroded, or contain sulfides and other contamination which may affect the quality of the spray deposit. The wire should be free from drawing/extruding lubricants, such as, grease, oils and graphite. Wires are provided in coils or on spools. Standard sizes and tolerances of diameter for the wires are given in Table 4. The wire should not overlap itself, so it can be freely fed to the gun without knotting. The cast or curvature of the wire should not be tight. Wire with a tight cast, if not properly straightened, may cause binding within the spray head or wandering of the electric arc. The wire must possess sufficient ductility and strength that on bending or pulling, it does not break. Materials should be properly packed, for protection during storage and transportation.

Table 4 Wire Diameters and Tolerances for Thermal Spraying

(*Clause* 5.1)

All dimensions in millimetres.

Sl No. (1)	Size (2)	Tolerance (3)
i)	1.60	+0–0.05
ii)	1.62	+0–0.05
iii)	2.00	+0–0.06
iv)	2.30	+0–0.06
v)	2.50	+0–0.06
vi)	3.00	+0–0.07
vii)	3.17	+0–0.07
viii)	3.48	+0–0.07
ix)	4.00	+0–0.07
x)	4.76	+0–0.07

Where a choice of the metal to be sprayed is possible, that metal should be selected which gives a coating with the lowest shrinkage rate (lowest co-efficient of expansion). An instance is the rebuilding of steel shafts where as general rule, high carbon steel (0.7) is preferred to low carbon mild steel (0.25 percent) which has a higher shrinkage rate and also oxidizes excessively during spraying with resultant tendencies to cracking. Where finished surface has to be of a metal with a high shrinkage rate and deposit has to be relatively thick, a metal having a low shrinkage rate should be chosen for building-up to within 0.5-1.0 mm of the finished size and the job may then be completed by spraying the desired wire having higher shrinkage rate. Where an 18/8 chrome-nickel stainless steel deposit is required to serve under corrosive conditions, it is necessary that the wire chosen should contain, in addition to these alloying elements, a stabilizer, such as, niobium or titanium. The use of molybdenum coatings must be restricted to building-up of only small amount of metal, such as, for instance restoring a press fit. In such cases, after initial bond coating is sprayed, further building-up is done with the coarseness of the spray reduced slightly by an increase of propellant air pressure. This results in a finer surface which may be finished speedily and more economically. Heavy thickness of sprayed molybdenum coating is not recommended both on considerations of cost and cracking of the deposit.

5.2 Powders

The powder feedstock must adhere to the same compositional requirement as that of the equivalent wire material. Powder though manufactured by the same method may be different from lot-to-lot. The differences may be particle configuration and size distribution. The quality of powders for thermal spraying depends on several basics. Many methods can be employed to manufacture powders, but the powders manufactured by the following two methods are recommended.

a) Mechanical processing of solid metals, and
b) Atomization of liquid metals.

Particle sizes and shapes can vary both within and between methods of manufacture. All powder particles for similar chemical composition may not behave in the thermal spraying gun in a manner identical to differently sized particles. Characterization of each powder must be done in detail for successful reproduction. Materials should be spray tested using the thermal spray devices intended for their deposition. The particle size distribution, apparent density and rate of flow are important parameters of powder to be characterized. The particle size distribution can be characterized by any of the standard methods available. The apparent density and rate of flow can be measured by the standard all flow meter. Testing of thermal spray materials includes determining the chemical and physical properties of each material and its behaviour in the thermal spray gun. Sprayability testing includes feed and deposition characteristics, plus an evaluation of the deposited products. Powder should be free flowing to prevent clogging of powder feeders, injectors, gun nozzles, or feed lines. Feed rate or spray rate is a measure of flowability. This is expressed as gram per minute (g/min). When determining spray rate, equipment configuration and gas pressures and flows should be specified, as they would for the actual spray operation. To begin a deposit efficiency test, powder flow should first be started, and the powder feeder should reach full speed (rpm), achieving a smooth flow rate. Conditions should stabilize within 10-20s; powder is then collected in a clean container for a prescribed period, such as, 1 min or 2 min. Efficiency may wary with target configuration, size and amount of overspray. Deposition efficiency is the ratio of sprayed material adhering to a large surface compared to the amount of material sprayed. Material counted shall be confined within the borders of that surface. Deposit efficiency, expressed as percentage is the ratio of coating mass to the mass of powder sprayed.

5.3 Gases

5.3.1 *Compressed Air*

Compressed air is the single most widely used gas in thermal spraying. The compressed air utilized should be proper quality to assure a reliable end product. Atmospheric air contains a wide variety of trace contaminants such as, water and oil. Typical operating systems include in-line water and oil filters located between the compressor and the spray device. These should be inspected and cleaned periodically to assure uncontaminated dry air. There should be an established in-house standard practice. The water content required for any particular grade of compressed air may vary with the intended use from saturated to very dry. If a specific water limit is required, it should be specified as a limiting dewpoint or concentration in ppm. Dewpoint is expressed at one atmosphere absolute pressure (101.3 KPa) in temperature degree Celcius. Techniques and instruments to determine dewpoint must be used to achieve greater control.

5.3.2 *Oxygen*

Water content and dewpoint both affect build-up quality. The user should establish in-house standard practices to maintain oxygen quality. Water content is determined as outlined in **4.3.1** and by using a dewpoint analyzer, in which the temperature of the viewed surface is measured at the time frost first begins to form.

5.3.3 *Fuel Gases*

The fuel gases refer to the combustible gases used in the flame spray process. The more common gases are acetylene, LPG, propane, and natural gas as outlined before. These gases must have a minimum purity of 99.6 percent. Acetylene should not have an excess of acetone vapours, because they lower the flame temperature and propagation rate. Acetylene should not be drawn off at a rate greater than 1.5 percent of the total gas available in the cylinder or at pressures greater than 103 kPa.

5.3.4 *Plasma Gases*

Plasma forming gases include argon (Ar), nitrogen (N_2), and hydrogen (H_2). Argon should be controlled for water content, dewpoint, and oxygen/nitrogen level. Nitrogen should be controlled for water content, dewpoint, and oxygen. Hydrogen should be controlled for water content, dewpoint, and oxygen level.

6 THERMAL SPRAYING OPERATION

6.1 Masking

Masking is an extremely important step in the overall process of thermal spray coatings application. When specific areas of a part must be thermally sprayed, the areas that are not to be coated must be masked. The masking method and materials used need to be selected based on the spray equipment and automation employed to apply the coating. The choice of masking material for each job is essential to the ultimate integrity of the coating and the total cost to process the part(s).

6.1.1 *Masking Materials*

Commonly used masking materials are silicon rubber, Teflon® tapes, aluminium foil, heat-resistant paints, metal, rubber, fibreglass sheet and carbon plugs or brushes. Metal is typically used for HVOF masking because the velocity of the particles sprayed by many HVOF systems cuts through common tape and masking compounds. The details of the materials for the thermal spraying are given in Table 5.

6.1.2 *Process Specific Masking*

6.1.2.1 *Flame spray*

Both wire and powder flame spraying utilize a flame to melt the feedstock and propel it to the substrate. The maximum temperature reached with combustion spraying is 2 500°C to 3 500°C. The masking materials used do not see the full effects of the temperature but, because of the flame, they should have the capability to withstand an open flame that will tend to heat the masking materials over 100°C.

Table 5 Details the Various Materials Used for Thermal Spraying

(*Clause* 6.1.1)

Sl No. (1)	Material (2)	Form (3)	Application (4)	Masking for Grit Blasting (5)	Masking for Spraying[1)] (6)	Removal (7)
i)	Fibreglass	Tape	Manual	Light only	All	Peel
ii)	Silicone rubber-coated fibreglass	Tape	Manual	Normal	All	Peel
iii)	Aluminium foil	Tape	Manual	No	All	Peel
iv)	Teflon®	Tape	Manual	No	All	Peel
v)	Electroplater's tape	Tape	Manual	No	All	Peel
vi)	Stop-off	Paint	Brush or spray	No	All	Water Rinse
vii)	Printer's ink	Paint	Brush or spray	No	All	Degreaser
viii)	Rubber sheet or preforms	Rod, sheet preforms	Manual	All	All	Peel
ix)	Rubber masks	Moulded pieces	Manual	All	All	Manual
x)	Brush or spray rubber compounds	Liquid	Manually spray	All	All	Soften in solvent and peel
xi)	Teflon®	Rod, sheet	Cut to fit Place manually	No	All	Manual
xii)	Fibreglass	Sheet	Cut to fit Place manually	No	All	Manual
xiii)	Carbon	Rod, bar	Cut to fit Place manually	No	All	Manual

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[1)] For processes other than HVOF.

6.1.2.2 *High velcity oxy-fuel (HVOF)*

The comments under flame spraying apply but, because of the velocity of the particles against the substrate, most masking materials other than metal cannot be used. The problem of spray build-up on mask can be eliminated by the use of acid and/or by mechanical removal for some of the materials. Masks made up of inconel and stainless steel though expensive can be reused. Masks made up of plain carbon steel should be discarded when the build-up of overspray becomes unacceptable, however, it is recommended to discard them after every job. Holes shall be masked with Teflon®, rubber plugs, or epoxy.

6.1.2.3 *Wire arc spray*

Because of the efficiency and high air flows of the wire arc spray process, the masking area is much cooler than with other spray equipment. A wider range of materials can be used due to the lack of flame. Care should be taken where thick coatings are applied, because heat from the high volume of sprayed metal can adversely affect any tape used on the part.

6.1.2.4 *Plasma spray*

The plasma spraying process melts powder in a partially ionized mixture at temperatures ranging from 5 000 to 17 000°C. This requires the masking materials selected to be the most heat resistant. Because the masking tends to lose definition on its edges during blasting, a separate masking layer may be required for the blast in order to maintain definition of the mask edge.

6.2 Spraying Procedure

The operating conditions recommended by the manufacturers of the thermal spray equipment shall be strictly adhered to. The practice of increasing spraying rates over those recommended by increasing gas pressures is, in particular, to be avoided since this could give rise to poor results. The gun or pistol should be started and adjusted with the spray directed away from the work. The work should be held in a device, such as, a lathe and made to rotate at a surface speed of 20 m/min. During spraying the pistol should be at a distance of 150 to 250 mm from the work depending upon equipment and size of wire used. The ends of the undercut sections should be sprayed first with the angle of impingement continually varying from about 30 to 60 degrees and then the remaining surface shall be sprayed. Whenever possible the spraying shall be done perpendicular to the surface and in no case the spraying angle will be less than 45° (*see* Fig. 11). Corners should be built-up from quarter to half the depth of undercut before proceeding further. The spraying process shall be continuous and rapid passes of 0.15 to 0.25 mm thickness should be applied progressively along the length of the surface sprayed. It is necessary to put on sufficient metal to allow for finishing (usually about 0.25 to 0.40 mm on radius over the finished size). The temperature of the work should on no account, be allowed to exceed 150 °C. Spraying should be stopped periodically if it is not possible by other means, to keep down the temperature within this limit. After spraying is completed, the work should be allowed to cool slowly to room temperature. The plugs for the oil holes and dummy keys for the keyways may be removed at this stage but where possible, it is recommended that these are not removed until the finishing operation is also over.

7 POST TREATMENTS

7.1 Sealing

Thermal spray coatings usually have a structure with inherent porosity that ranges from less than 2 to more than 15 volume percent depending on the process by which the coating is deposited and the material sprayed. At least some of this porosity is interconnected. In many cases, coatings are exposed to corrosive fluids (liquids or gases) or hydraulic fluids that can infiltrate the pores, resulting in fluid leakage or corrosion throughout the coating or of the base material. These conditions can contribute to the premature failure of the coating. Many such cases, therefore, require the coating to be sealed. Sealing a coating may also help to reduce particle pullout from the surface during finishing for coatings with low cohesive strength. Sealants are used on thermally sprayed machine parts to prevent corrosive attack on parts, such as, high pressure hydraulic rams, and on pump shafts to prevent fluid seepage into the packing. They are also sealed to ensure a better and cleaner ground finish. Sealing before grinding prevents debris from entering the pores of the coating and facilitates wash cleaning after grinding. The sealant materials generally used are wax, phenolic resins and methylacrylate. Wax is inert material used to prevent infiltration of liquids and to provide lubricity at low service temperature. It melts at 93°C. It is inert to salt and fresh water. It will not resist organic solvents and hydrocarbons, and when used in lubricated service will be gradually displaced from the coating pores by oils and greases. A wax sealant cannot be used for hydraulic rams with fluids which will dissolve it.

Phenolic resins in solution are widely used as sealant. Composition variations are available in air drying and baking types. Service temperature for these materials range from 150-260°C. When the resin is cured it exhibits good resistance to organic solvents and weak acids. A typical use of air drying phenolics is the sealing coatings applied to high pressure hydraulic rams. Methylacrylate sealing coatings can be used in application up to 20 MPa and service temperature of around 150°C. They are resistant to water, oils, fuels, hydraulic fluids, and solvents. To ensure as complete a sealing of the coating as possible, it is necessary to apply the sealant material as soon after coating as possible and prior to surface finishing. Generally, the sealant shall be applied after spraying and before finish grinding or machining operations. For some applications, however, sealing shall be done after finishing. However, surface is less porous after machining and the measured penetration is significantly less.

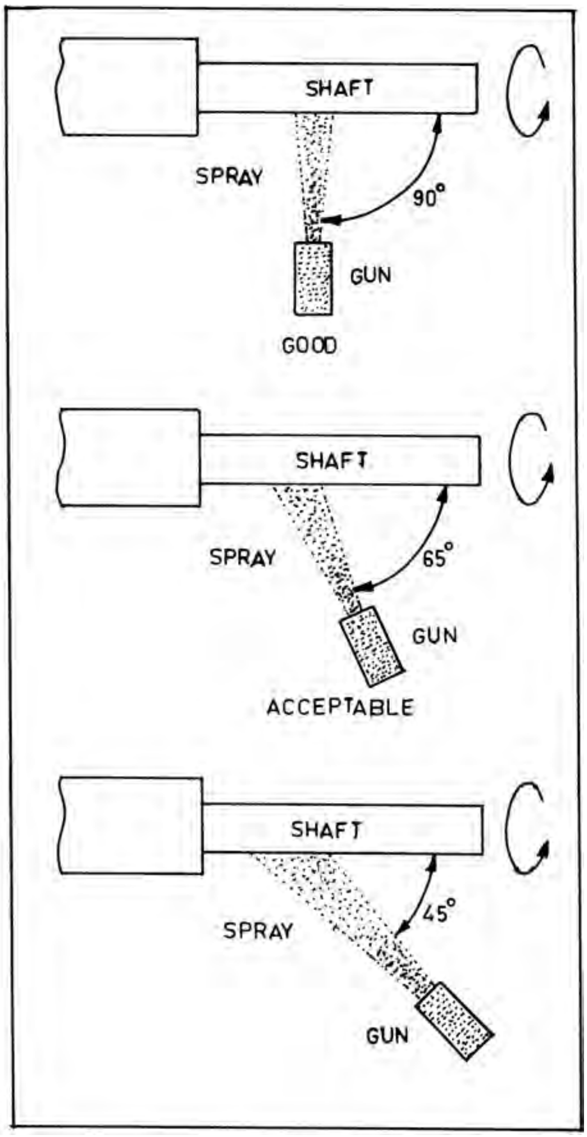

FIG. 11 THERMAL SPRAY STREAM POSITIONS

7.2 FINISHING

Thermal spray deposits can be ground and finished in many ways. The method chosen can range from simple hand polishing operations, to hand grinding with coated abrasive belts, or to more complex machining, such as, use of precision grinders. Factors which influence the choice of finishing method include type of material to be ground, shape of part, finish and tolerance required, type of equipment available and economics. Generally, with most spray applications, the finer and more uniform the material applied, the better is the final finish.

7.2.1 *Machining*

Carbide tools are generally used on machinable thermal spray coatings. Tool angles, and surface speeds and feeds are critical in the success of the machining operation. Improper tool angles and tool pressure can result in excessive particle pull-out and destruction of the coating-substrate bond. Properly sharpened tools can machine hard fused coatings with relative ease. Machining of a spray coating shall start with the removal of heavy overspray at the end of the coated area. Rough machining of the coating is accomplished at the same or slightly slower speeds (surface feet/ minute) and with approximately twice the amount of feed (inches per revolution) of finish machining. The depth of the cut can range up to 0.76 mm thickness. Approximately, 0.13 to 0.25 mm is recommended to be left for finishing. Removal may require multiple passes. A properly sharpened tool will wear flat at the contact point. This flattening has the effect of smearing the metal and can actually provide a better finish than would result with a sharp tool with a radius. However, caution must be taken to not let this flattening become excessive which may result in rapid heat build-up and particle pull-out. Newer cutting tools like cubic boron nitride (CBN), oxide coated carbides, ceramics and diamonds are recommended for successfully machining very hard metals at faster rate. For optimum results when using these cutters, the use of rigid machinery is mandatory.

7.2.2 *Grinding*

Material finish and tolerance requirements may dictate grinding as the only practical means of finishing thermal sprayed parts. Machines commonly used are outside diameter grinders, surface grinders, and internal grinders. When using any abrasive medium to grind and polish, it must be kept in mind that thermal sprayed coatings are vastly different from the same material in wrought or cast form. If wheels of excessive hardness are used, or if they do not cut freely, individual particles can be pulled from the coating surface. Excessive grinding pressure should not be applied because the ductility of the sprayed coating is low which may result in shifting or displacement of the spray materials. The grinding variables include the wheel speed, work speed and area of contact. A proper understanding of these variables is essential to achieve optimum surface finish and manufacturer's recommendation on same must be followed. Always use the sharpest wheel possible. Sharp wheels cut rapidly without overheating. The sharpness of the wheel depends on grit size and grain type. Generally silicon carbide or diamond must be chosen depending on the coating to be ground. Fine grit abrasives will penetrate hard materials easier than coarse grit abrasives. Grits normally used to grind sprayed deposits range from 37 to 180 µm, although smaller sizes may be used to generate finer finishes. Choose wheels with structures and grades which provide free cutting action. Wheel structure is related to the spacing between the individual abrasive grains within the wheel. Wheels with open structure tend to cut more freely. Harder wheel last longer but they cut more slowly, generate more heat and require more frequent dressing than softer wheels. Choose a bond type best suited to the operation and equipment. Vitrified bonds, because of their porosity, rigidity and strength can provide high stock removal rates and precision tolerances. Most vitrified wheels, however, are limited to a safe operating speed of 33 m/s. They should only be used if it has been ascertained that the operating speed of the machine does not exceed the safe operating speed of the wheel. Resinoid bonds are designed to operate at speeds of 48 m/s for diamond resin bonded wheels. They are used for rapid stock removal and to generate fine finishes. Although resin bonded wheels operate safely at high speeds, the machine speed should never exceed the indicated safe operating speed. A proper knowledge and understanding of both the machines and equipment is essential for achieving proper surface finish. The following additional guidelines must be followed to achieve proper surface finish:

a) Use soft, free cutting wheels. Chances of burnishing and pull-out will be greatly reduced.
b) Maintain the wheel face in a clean and sharp condition.
c) Observe proper dressing techniques.
d) Use coarse grit wheels for maximum stock removal and fine grit wheels for finishing.
e) Attempting to generate fine finishes with coarse grit wheels that have been dressed closed can result in particle pull-out, smearing, and burnishing.
f) Use light cuts. Sprayed coatings are usually very thin. Excessive grinding pressure can cause delamination of the sprayed surface or pull-out of surface particles.
g) Do not 'spark out' on the final pass; this tends to glaze or dull the wheel face.
h) Grind wet whenever possible. Improved finishes, less chance of burnishing, and less contamination will result.
j) Use finer grit wheels on dense, hard to penetrate, sprayed coatings.
k) Always keep the coating under compression. By cutting down through the sprayed surface towards the substrate, delamination and pull-out will be minimized.
m) To a great extent, the effectiveness of the thermal spray coatings is dependent on the finishing techniques employed.

8 INSPECTION

Inspection is done after the finishing operations are over. Both destructive and non-destructive methods of evaluation can be utilized.

8.1 Destructive Tests

In destructive testing finished parts are destroyed and a sample of the coating is removed and prepared for metallographic examination. Although this provides the most accurate assessment of coating quality, it is often somewhat impractical when the coated parts are large, costly, or limited in number. In such cases, a sample of the coating should be sprayed along with the actual part and used for evaluation. Sample test coupons so prepared are designed to provide information on tensile bond strength, microstructure, bend strength, hardness, etc. Information gathered on separate sample coupons, however, will always be somewhat subjective because it is indirect; that is, the data may not represent the coating as it was applied to the actual part if spraying was done at a different time or more likely onto a different substrate shape or substrate material. If possible, the sample should be sprayed simultaneously with actual parts, using the same substrate material and surface preparation. The destructive tests performed on the test coupon are given below and for more information literature related to the same may be referred.

8.1.1 *Tensile Adhesion Strength*

The tension adhesion strength test shall be done. The bond tensile strengths in psi, ksi, or MPa are recorded. An absolute minimum of three tests shall be carried out, although five or more are better from statistical standpoint. The bond strength of the adhesive used must also be measured as a part of each test batch. After failure, the sample surfaces must be examined to study the locus of failure. This can provide insight into the nature of the failure, within the adhesive, at the coating substrate interface (adhesive failure), or within the coating (a mixed mode failure).

8.1.2 *Metallography*

Samples of the coating/substrate are sectioned, mounted, polished, and studied using a light optical microscope, generally at magnifications ranging from 50 to 100×. From analysis of a polished coating cross section, density, melting efficiency (unmelted particles), oxide content and distribution, thickness, grain size (which may require etching to reveal the grain structure), bond-line integrity and microhardness can be determined.

8.1.3 *Bend Testing*

Coatings shall be sprayed onto a 7.87 mm thick coupon and it will be bent over a 25.4 mm diameter shaft to -90° and examined for cracking, chipping, and peeling as indicators of bond integrity and coating ductility.

8.2 Non-destructive Tests

Such testing/examination is done directly on the finished part without damaging its appearance or functional capability. It is possible to test every part and achieve 100 percent quality assurance. Non-destructive testing does not always provide quantitative information normally gathered by metallography or tensile bond testing. One must know the limitations for detecting each important characteristic, such as, debond size or debonds along edges. Calibration standards for each material/ geometry are required. The non-destructive tests performed on the part are given below and for more information literature related to the same may be referred.

8.2.1 *Thickness*

When the substrate size and shape permit, simple calipers or micrometers can be used. Ultrasonic thickness measuring devices can be used on more complex geometries and for better accuracies.

8.2.2 *Surface Texture*

Visual inspection and stylus-tracing profilometers can be used for measuring the same.

8.2.3 *Micro-Hardness*

Vickers micro-hardness at 300 g load shall be measured and reported. The impression should be spread over several particles. A minimum of three readings must be measured and their average reported.

9 HEALTH AND SAFETY

There are some health and safety concerns associated with thermal spray coating processes, as with most industrial processes. In general they are similar to those associated with welding processes. All plant or laboratory directives shall be followed. None of the thermal spray processes shall be attempted without proper training of all of the personnel involved and careful consideration of any hazards associated with the particular materials being used to prepare for or produce the coating. Proper care and maintenance of the equipment, including all gas and electric lines, will greatly reduce any hazards. In addition, design and procedure reviews for safety by qualified engineers are advisable. These should include the ancillary processes of surface preparation, part handling, and finishing as well as the coating process itself. In general, the hazards of thermal spray operations are associated with the following:

a) Gases,
b) Liquids,
c) Electrical equipment,
d) Feedstock material,
e) Fumes and dust,
f) Heat, sound and light, and
g) Robotics and other mechanical equipment.

9.1 Dust and Fumes

All thermal spray processes produce dust and fumes, so operators must be protected and the dust and fumes collected. When possible, the coating process shall be conducted in a cubicle equipped with ventilation and dust collection equipment and with the operators outside. Each thermal spray process has its own airflow requirement to provide adequate ventilation, and the equipment manufacturer guidelines shall be followed. Nonetheless, dust monitors should be periodically used to ensure that the ventilation system is working properly. If the operators must be in the cubicle or the coating must be done in the open, the operators should wear respirators. It is no longer considered adequate to rely only on air flow away from the operator to provide adequate protection. The type of respirator used depends on the material being deposited. The effluent from the dust collection system should be periodically monitored to ensure compliance with all regulations.

9.2 Noise

Noise generated by thermal spray processes ranges from about 80 dB for some of the flame spray processes to over 140 dB for plasma spray processes. Individual ear protection is adequate for the former, but the latter must be operated in sound-reducing cubicles. Actual sound pressure levels depends strongly on specific spray environments, such as, booth size, wall material, and construction details. Sound levels at the operator's position should be measured and compliance with all regulations ensured. In addition, all personnel in the vicinity of the spray operation should have their hearing checked periodically.

9.3 Light Radiation

The spectrum of light emitted by the thermal spray devices ranges from the far infrared to extreme ultraviolet. Excessive exposure to the bright emissions from thermal spray guns can cause both acute injuries and chronic conditions, such as, cataracts. Helmets, hand-held shields, face shields, and safety glasses or goggles should be used to protect the eyes, face, and neck during thermal spraying. Shade 5 lenses may be sufficient for some flame spray processes, but shade 12 is required for plasma spray and wire arc. Fire-retardant, closely woven fabrics should be worn to protect the skin from burns. Burns can be caused by heated particles bouncing from the substrate, hot gases, or light. Ultraviolet radiation will burn exposed skin and penetrate loosely woven fabrics, causing burns similar to severe sunburn in minutes.

9.4 Heat

Thermal spray guns, especially high-velocity oxy-fuel (HVOF) devices, generate substantial quantities of heat. Without adequate ventilation, the booth can quickly become overheated, and excessive heat can damage the ductwork and dust filter system. It is recommended that the total exhaust airflow be sufficient to keep the exhaust air temperature below 40°C; however, exceptionally high flow velocities exceeding 91 m/min at the front face of the spray hood may interfere with the spray operations. Thermally insulated gloves and handling tools shall be used to handle hot work pieces and tooling. Cotton clothing is recommended as it does not melt and does not support combustion as readily.

10 ACCEPTANCE LIMITS

Acceptance limits related to the porosity, bond shear strength, etc, of the thermally sprayed coatings shall be mutually agreed between the thermal spray contractor and the asset owner.

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This Indian Standard has been developed from Doc No.: MTD 12 (4958).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

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Published by BIS, New Delhi